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Morphometric Analyses with Eight Subspecies of Striped Field Mice, *Apodemus agrarius* Pallas (Rodentia, Mammalia), in Asia: The Taxonomic Status of Subspecies *chejuensis* at Cheju island in Korea

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아시아에 서식하는 등줄쥐, *Apodemus agrarius* Pallas(설치목, 포유강) 8개 아종의 형태적 형질들을 사용한 다변량 분석 : 한국의 제주도의 아종 *chejuenesis*의 분류학적 위치

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적 요

한국의 제주도에 서식하고 있는 등줄쥐의 한 아종인 *Apodemus agrarius chejuensis*의 분류학적 위치의 파악을 위하여, 아시아에 서식하는 등줄쥐중에 터키, 중국, 대만, 만주 및 한국에서 채집된 8아종(*agrarius, ningpoensis, pallidior, chevrieri, insulaemus, manchuricus, coreae* 및 *chejuensis*), 311마리의 표본들을 사용하였다. 4개 외부형질과 27개 두골형질들을 측정하였고 cluster, principal components 및 discriminant 분석등의 다변량분석을 수행하였다. 4개형(form)으로 나뉘어졌는데, *chejuensis*는 가장 큰 형이었고, 큰 형인 *chevrieri*는 Wang (1985)에 의하여 종으로도 기술된 바가 있다. 중간 크기의 형과 작은 크기의 형은 각각 *coreae*와 나머지 5개 아종(*agrarius, ningpoensis, pallidior, insulaemus* 및 *manchuricus*)이었으며, 연속적 변이를 나타냈다. 제주도의 *chejuensis*(가장 큰 형)는 등줄쥐의 다른 6개 아종(중간과 작은 크기의 형들)과 형태적 형질에 있어서 불연속적 차이를 보였으므로 신종으로 판단되지만, 신종으로의 기재를 위해서는 연구가 더 필요하다고 결론지었다.

Key words: Systematics, morphometry, rodents, *Apodemus agrarius*, Asia

INTRODUCTION

The genus *Apodemus* is a fairly distinctive genus composed of 12 species and it is confined to the Palaearc-

tic region and northern part of the Oriental region. It is generally agreed that *Apodemus agrarius Pallas* (striped field mice) is a sole member of the subgenus *Apodemus* inhabiting from West Germany to Korea. However, the subclassification of *Apodemus agrarius* is in confusion. Corbet (1978) noted that most of subspecies of *A. agrarius* were designated by differences in pelage colour and/or mean body size and he summarized 23 subspecies into three subspecies (*agrarius*, a western subspecies including 12 named subspecies; *ningpoensis*, an eastern subspecies including *pallidior, insulaemus, manchuricus, coreae, chejuensis*, and three named subspecies: and *chevrieri*, a southern Chinese subspecies). Wang (1985) performed the analyses with penile bones, papilla lingualis, and serum proteins of three subspeices (*chevrieri, ningpoensis, pallidior*) of *Apodemus agrarius* in Sichuan, China, and concluded that *A. chevrieri* (= *A. agrarius chevrieri*) is a species which is distinct from *A. agrarius ningpoensis* and *A. agrarius pallidior*. Koh (1987) carried out multivariate analyses with external and cranial characters of two subspecies of *A. agrarius* in Korea and noted that *A. agrarius chejuensis* from Cheju island is distinct from *A. agrarius coreae* (the former is a large-size group and the latter is a small-size group). The methods of numerical taxonomy based on equal weighting and overall similarity seemed inapplicable in defining higher categories above the species level (Farris, 1966). On the other hand, Flake and Turner (1968) stated that the numerial approach offers potential for the resolution of taxonomic problems for populations at infraspecific level.

The objective of this paper is to analyze morphometric characters of samples of *Apodemus agrarius* from 20 localities in Asia, representing eight subspecies (*agrarius, ningpoensis, pallidior, insulaemus, manchuricus, coreae, chejuensis*, and *chevrieri*), in order to determine the subspecific status of *A. agrarius chejuensis* at Cheju island, Korea.

MATERIALS AND METHODS

Materials

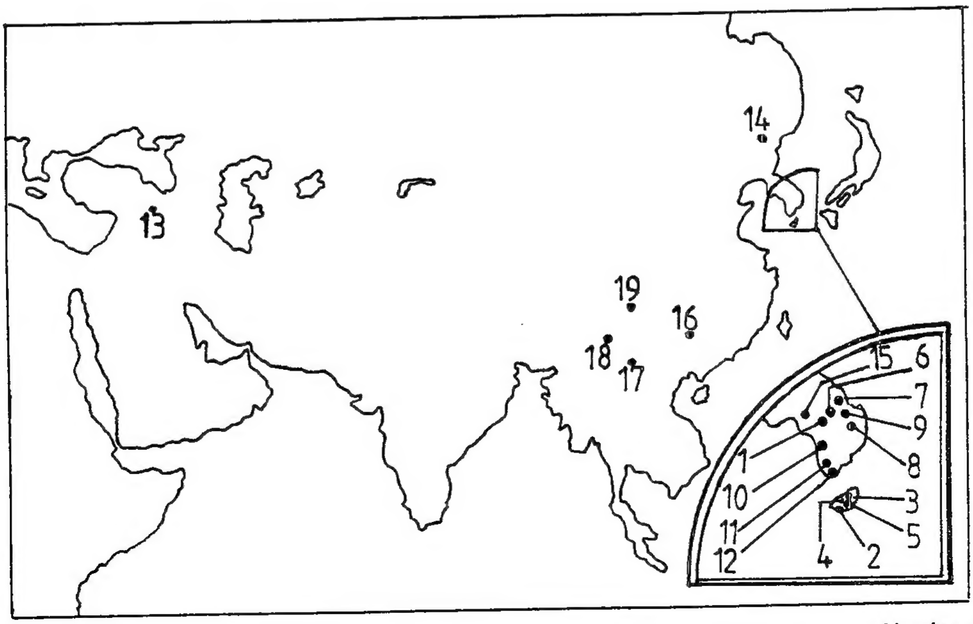

Fig. 1. A map showing 20 localities (OTU's) in *Apodemus agrarius*. For the subspecies name and locality of each OTU see Table 1.

Three hundred and ninety eight samples of *Apodemus agrarius* from 20 localities in Asia, representing eight subspecies, were measured as shown in Table 1 and Fig. 1.

Multivariate analyses

Analyses were based on four external and 27 cranial characters (for details see Koh, 1983) and samples from each locality were grouped as Operational Taxonomic Units, OTU's (see Table 1). Sexual variation in striped field mice was not significant, whereas significant age variation was revealed (Koh, 1983). Therefore, each specimen was assigned to one of five age classes, juvenile, subadult, young adult, middle-aged adult, and old adult based on the eruption of upper third molar, degree of tooth-wear, and pelage colour (for details see Koh, 1983). Three hundred and ninety eight samples were classified into 55 juveniles, 165 young adults, 146 middle-aged adults, and 32 old adults (see Table 1) and 311 samples of young and middle-aged adults were used for further analyses.

All computations were made using Chungbuk University HP-3000/58 computer. Sample statistics such as mean, standard deviation, and kurtosis were calculated by ELEMSTAT program of Interactive Statistical Programs (ISP). For ordination analyses, principal component analysis (PCA) was performed from the means

Table 1. Specimens of *Apodemus agrarius* used. SA, YA, MA, and OA indicate subadult, young adult, middle-aged adult, and old adult, respectively.

Subspecies	OTU	Locality	No. of sample				
			SA	YA	MA	OA	Total
coreae	1	Chongju, Chungbuk, Korea	37	43	42	9	131
chejuensis	2	Mosulpo, Cheju, Korea		3	9	2	14
〃	3	Jeju, Cheju, Korea		3	3		6
〃	4	Sanchondan, Cheju, Korea		8	10	1	19
〃	5	Yongsil, Cheju, Korea	2	6	3		11
coreae	6	Mt. Weolak, Chungbuk, Korea	6	4	13	3	26
〃	7	Mt. Taebaek, Kyongbuk, Korea	2	6	8	3	19
〃	8	Mt. Palgong, Kyongbuk, Korea	4	4	9	4	21
〃	9	Munkyong, Chungbuk, Korea	1	7	12	2	22
〃	10	Kunsan, Chonbuk, Korea		1	6	1	8
〃	11	Youngkwang, Chonnam, Korea		6	2		8
〃	12	Jin island, Chonnam, Korea	1	12	6		19
agrarius	13	Istanbul, Turkey		7	4	1	12
manchuricus	14	Kirin, Manchuria	2	5	2	1	10
〃	15	Munsan, Kangwon, Korea		2	2	1	5
ningpoensis	16	Yuchow, Hunan, China		7		1	8
Chevrieri	17	Lichiang, Yunnan, China		18	4	2	24
pallidior	18	Taofushien, Sikang, China		1	5		6
〃	19	Wanhsien, Szechnan, China		16	4	1	21
insulaemus	20	Taipei, Taiwan		6	2		8
Total			55	165	146	32	398

of 31 characters using subprogram PCAS of ISP. However, the data were singular in the analysis. Therefore, 12 characters (1,5,8,12,13,15,16,18,21,24,28, and 31) showing significant difference among means of four OTU's in *A. agrarius coreae* were selected (see Koh, 1985) and used. Discriminant analysis with the measurements of 31 characters was also carried out by DISCRIM program of Statistical Packages for the Social Sciences (SPSS; Nie *et al.*, 1975). The group centroids were only shown here. For cluster analyses, SPSS/PC+ programs were used. Raw data were first sandardized and OTU's were grouped by single, average, and complete linkage methods.

RESULTS

Two dimensional configurations of 20 OTU's, eight subspecies, of *Apodemus agrarius* by PCA with 12 character means are shown in Fig. 2. The correlations between original characters and the principal components are given in Table 2. Two dimensional plottings from discriminant analysis with 311 adult measurements of *Apodemus agrarius* (20 OTU's) are shown in Fig. 3. The correlations between original

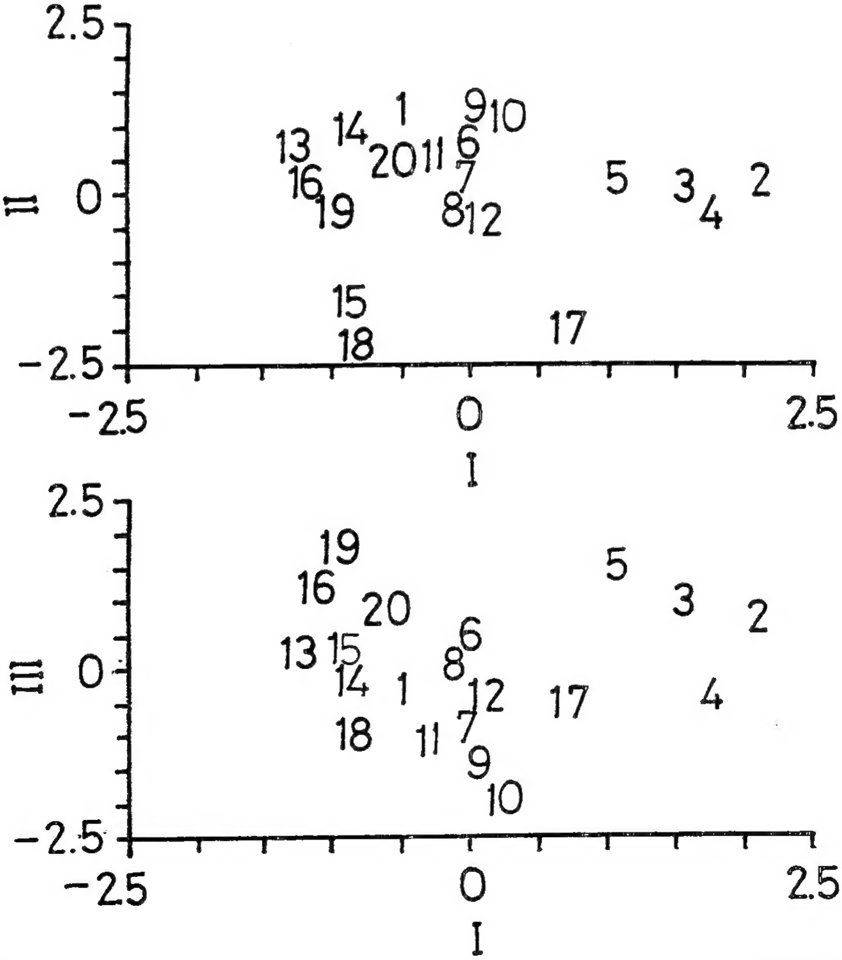

Fig. 2. Projections of 20 OTU's of *Apodemus agrarius* by principal component analysis with 12 character means. Numerals indicate OTU number.

Table 2. Principal components I, II, and III expressed as correlations between characters and individual components from the analysis of 20 OTU's of *Apodemus agrarius*.

Character	Factor* I	Factor* II	Factor* III	Character	Factor* I	Factor* II	Factor* III
1	0.96	0.04	0.04	5	0.93	0.08	-0.19
8	0.88	0.34	-0.14	12	0.94	-0.08	0.19
13	0.78	-0.55	0.20	15	0.65	-0.70	0.18
16	0.88	-0.10	-0.25	18	0.76	0.12	0.60
21	0.86	0.23	0.04	24	0.92	0.23	-0.24
28	0.78	0.36	0.07	31	0.82	-0.17	0.02
% trace					72	10	5

*Factors I,II,III represent 72,10 and 5 per cent of the variance, respectively.

Table 3. Discriminant functions I,II, and III expressed as correlations between characters and individual functions from the analysis with 311 adult measurments of *Apodemus agrarius* (20 OTU's).

Character	Function* I	Function* II	Function* III	Character	Function* I	Function* II	Function* III
1	-0.14	0.34	0.62	2	-0.99	0.28	0.51
3	-0.20	-0.21	2.48	4	-0.24	0.47	0.51
5	-0.45	0.66	0.75	6	-0.25	1.06	1.37
7	-0.23	1.41	0.43	8	-1.74	0.88	0.91
9	0.94	0.39	1.41	10	0.07	0.71	0.97
11	-0.02	0.84	0.65	12	-0.23	1.29	1.69
13	0.65	1.42	1.24	14	-0.24	0.67	1.23
15	0.71	2.23	1.00	16	-0.26	1.33	0.65
17	-0.28	1.27	0.57	18	-0.04	0.23	0.61
19	-0.19	0.32	0.79	20	-0.42	0.49	1.98
21	-0.32	1.16	0.65	22	0.00	0.58	0.69
23	1.28	1.66	2.02	24	-0.44	0.55	0.49
25	0.09	0.49	1.40	26	1.04	1.80	0.85
27	1.42	-0.13	1.68	28	-0.02	0.01	0.02
29	-0.03	0.32	0.03	30	0.02	0.01	0.03
31	-0.04	0.58	0.08				
% trace	32	25	11				

*Functions I,II, and III represent 32, 25, and 11 per cent of the variance, respectively.

characters and the discriminant functions are given in Table 3. The 20 OTU's of *Apodemus agrarius* were also grouped by cluster analyses of single, average, and complete methods, as shown in Fig. 4.

In summary, four forms were revealed in the analyses with 20 OTU's (eight subspecies) of *Apodemus agrarius:* I, a largest-size form, OTU's 2, 3, 4, and 5 (*chejuensis*); II, a large-size form, OTU 17 (*chevieri*); III, a medium-size form, OTU's 1, 6, 7, 8, 9, 10, 11 and 12 (*coreae*); IV, a small-size form, OTU's 13 (*agrarius*), 14 and 15 (*manchuricus*), 16 (*ningpoensis*), 18 and 19 (*pallidior*) and 20 (*insulaemus*). The medium-size form (III) and the small-size form (IV) are continuous in their morphometric characters.

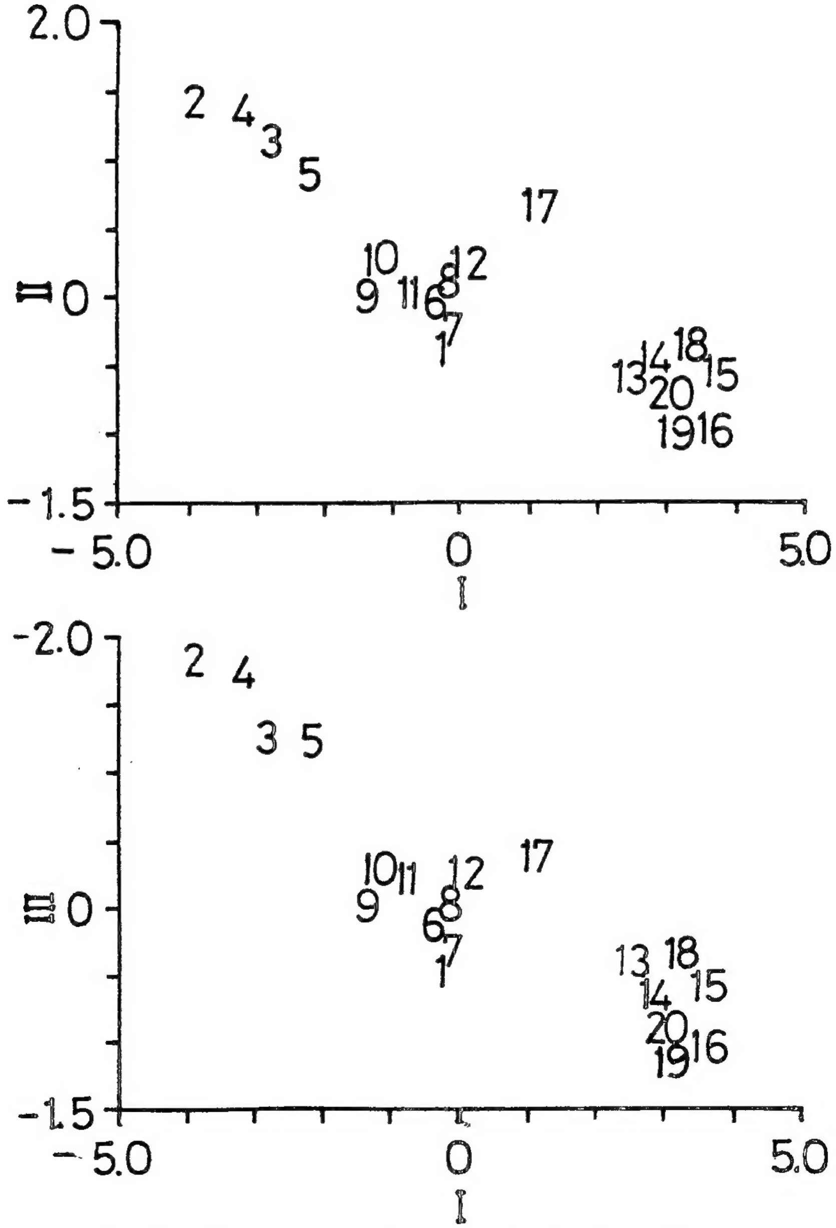

Fig. 3. Plottings of 20 OTU's of *Apodemus agrarius* by discriminant analysis with 311 individual measurements. Numerals indicate group centroid of each OTU.

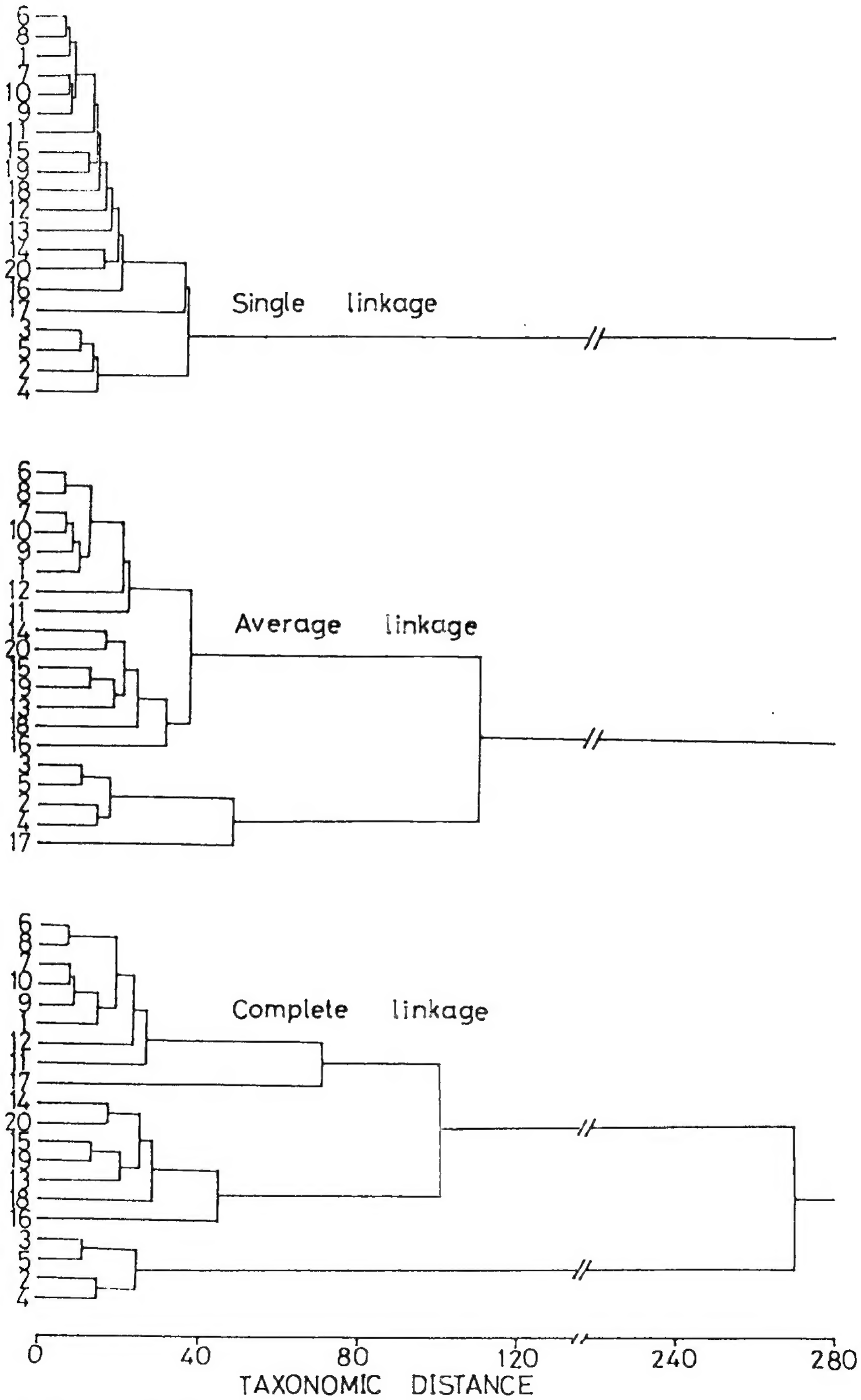

Fig. 4. Grouping of 20 OTU's of *Apodemus agrarius* by cluster analyses of single, average, and complete linkage methods with 31 character means.

DISCUSSION

Boyce (1969) noted that average linkage or UPGMA represents a distance matrix of random points better than either complete or single linkage. The relationships between close neighbors are frequently distorted in an ordination, especially one based on principal component analysis (Rohlf, 1970). Principal component analysis makes no assumption about the existence of grouping among the OTU's (Clifford and Stephenson, 1975), whereas discriminant function analysis ordinates two or more a priori defined groups as that there is minimum overlap and maximum separation among them (Thorpe, 1981). Furthermore, Sneath and Sokal (1973) stated that there are no satisfactory methods for telling whether clustering or ordination is most appropriate.

Four forms were revealed by clustering (Fig. 4), PCA (Fig. 2), and discriminant analysis (Fig. 3) with the morphometric characters of *Apodemus agrarius* in Asia, indicating that marked difference among the four forms resulted in the same conclusion even with different methods [A largest-size form is a subspcies *chejuensis:* a large-size form, a subspecies *chevrieri:* a medium-size form, a subspecies *coreae:* and a small-size form, five subspecies (*agrarius, manchuricus, ningpoensis, pallidior,* and *insulaemus*)]. Ellerman (1941) considered that *Apodemus agrarius chevrieri* represented a distinct species and Wang (1985) confirmed it from the analyses with the penile bones, papilla lingualis, and serum proteins. In the present study, *A. chevrieri (= A agrarius chevrieri)* is the large-size form and *chevrieri* appeared to be distinct in morphometric characters from other seven subspecies of *Apodemus agrarius* as mentioned above (see Figs. 2,3, and 4).

Corbet (1978) summarized 23 subspecies of *Apodemus agrarius* into three and designated a subspecies *ningpoensis* as eastern form, including *chejuensis, coreae, manchuricus, pallidior,* and *insulaemus,* and a subspecies *agrarius* as western form. In this study, *coreae* (the medium-size form) is somewhat larger than *manchuricus, pallidior, insulaemus, ningpoensis,* and *agrarius* (the small-size form), although their difference is clinal, and it is concluded that *coreae* is a subspecies of *A. agrarius.* Corbet (1978) also noted that insular subspecies (*insulaemus* in Taiwan and *chejuensis* in Cheju island) are rather large but are not very distinctive. Continental islands, which are connected to the mainland during the Pleistocene, became isolated about 10,000 years ago (Wilcox, 1978; Jameson, 1981) and Taiwan and Cheju islands are continental islands. Geographically isolated populations may be species or subspecies (Wiley, 1982) and it is preferable for various reasons to treat allopatric populations of doubtful ranks as subspecies (Mayr, 1969). In this study, it is confirmed that *A. agrarius insulaemus* (the subspecies of a small-size form) is not different in morphometric characters from mainland forms of China.

Jones and Johnson (1965) stated that the subspeciation of *Apodemus agrarius* in Korean mainland was not clearly defined: They recognized four subspecies in Korea [*chejuensis* in Cheju island, pallescence in the coastal lowlands of southern and southwestern region, *coreae* throughout the major portion of the peninsula, and *manchuricus* in the extreme northern part]. Koh (1986) performed multivariate analyses with morphometric characters and concluded that *pallescence* is a synonym of *coreae,* and *chejuensis* is distinctively larger than *coreae,* Koh (1989) performed morphometric analyses with *Apodemus agrarius* from islands in southwestern coasts of the Korean peninsula and concluded that samples from Wan and Bogil islands formed a large-size group with those from Cheju island, whereas samples from Jin and Hajo islands formed a small-size group with those from the mainland Korea.

In the absence of direct information on reproductive isolation, a full understanding of both individual and geographic variation is more helpful in the avoidance of error for the decision on species level than is anything else (Mayr, 1969). Crowson (1970) noted that a discontinuity in characters of structure will

normally show when members of two different species are compared. Ross (1974) stated that when there is no intermediate between two parapatric groups they are different species.

In this study, *Apodemus agrarius chejüensis* is the largest-size form, which is quite different from other seven subspecies of *Apodemus agrarius* in Asia (see Figs. 2,3, and 4) and *chejuensis* appeared to be a distinct species. However, studies that incorporate both molecular and morphological data will provide much better descriptions and interpretation of biological diversity than those that focus on just one approach (Hillis and Moritz, 1990). Therefore, it is concluded that molecular studies with the samples of *Apodemus agrarius* in the Korean peninsulla are necessary before the final decision on the specific status of *A. agrarius chejuensis* is made.

ABSTRACT

In order to determine the taxonomic status of *Apodemus agrarius chejuensis* from Cheju island in Korea, three hundred and eleven samples of eight subspecies of striped field mice (subspecies *agrarius, ningpoensis, pallidior, chevrieri, insulaemus, manchuricus, coreae,* and *chejuensis* of *A. agrarius* Pallas) in Asia, collected from Turkey, China, Taiwan,, Manchuria, and Korea, were used. Four external and 27 cranial characters were measured and their measurements were utilized for multivariate analyses such as cluster, principal component, and discriminant analyses. Four forms were revealed. A largest-size form was *chejuensis,* whereas a large-size form was *chevrieri.* A medium-size form and a small-size form were *coreae* and other five subspecies (*agrarius, ningpoensis, pallidior, insulaemus,* and *manchuricus*), respectively, but their differences were clinal.

A discontinuous gap was revealed between *chejuensis* (a largest-size form) and six subspecies (a medium-size form and a small-size form). Although *chejuensis* appeared to be a distinct species, it is concluded that molecular analyses are necessary in order to describe it as a new species.

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